Chapter 7

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Carbon Lockdown's Potomac Project in Northern Maryland.
By Ning Zeng

Chapter 7 | Current levels of CDR

Current annual removal from the atmosphere, combining conventional and novel methods, totals around 2,200 $MtCO_2$ per year. The vast majority of this removal comes from afforestation and reforestation. At the same time, another 330 $MtCO_2$ per year, withdrawn from the atmosphere in previous years by trees, is transferred to other forms of durable storage in wood products. Novel CDR activity at 2.0 $MtCO_2$ per year is around 1,000 times smaller than conventional CDR, but it is growing.

Key insights

- Global conventional CDR from afforestation and reforestation has averaged 2,200 $MtCO_2$ per year (with a model range of between 1,800 $MtCO_2$ and 2,600 $MtCO_2$ per year) over the decade from 2014 to 2023. Bookkeeping models, which quantify CO_2 removals and emissions related to land use, and adjusted national inventories broadly agree on this global total.

- The countries that have generated the largest amounts of CDR from afforestation and reforestation from 2014 to 2023 are China, the United States, the European Union, Brazil and the Russian Federation, according to bookkeeping models.

- Some CDR activities involve transferring carbon that was captured in a previous year from one type of storage to another. The transfer of carbon from managed forests to durable wood products averaged 780 $MtCO_2$ per year from 2014 to 2023. After accounting for the CO_2 re-emissions from the decay of existing wood products, the net increase in carbon stored over this period is estimated at 330 $MtCO_2$ per year.

- Activity from novel CDR methods is estimated to total 2.04 $MtCO_2$ globally in 2025, up from 1.4 $MtCO_2$ in 2023. While average annual growth was 36% per year from 2020 to 2025 – led by biochar – the volume from some novel CDR methods declined from 2023 to 2025.

- Biochar (1.46 $MtCO_2$ of which 0.97 $MtCO_2$ is a net transfer of woody carbon) and BECCS (0.51 $MtCO_2$) were the largest contributors to novel CDR activity in 2025, followed by biomass direct storage (0.05 $MtCO_2$). Enhanced weathering (EW) and mineral products contributed roughly equal amounts (0.0038 $MtCO_2$ and 0.0022 $MtCO_2$ respectively).

- Projects operating and under construction suggest a further increase in novel CDR capacity to approximately 8.4 $MtCO_2$ per year by 2030. Despite this, real-world increases in removal in recent years have achieved only 20% of projected capacity.

This chapter presents the latest estimates of current and recent CDR levels, as well as a projection for near-term change in novel CDR capacity based on projects operating or under construction. Our assessment brings together multiple sources of data across CDR methods, harmonized within a consistent framework, to provide a comprehensive and robust estimate of current CDR levels. It provides a brief overview of the assessment framework, with further methodological details available in the Technical Annex. Estimated annual levels of CDR are given for conventional methods (principally afforestation and reforestation) and for novel methods (e.g. biochar, BECCS, DACCS, enhanced weathering, biomass direct storage). Some CDR activities involve transfers of carbon captured in previous years from one form of durable storage (usually woody biomass) to another. We also discuss the pipeline of future CDR in the coming three years based on existing projects and those under construction.

7.1 Methods for estimating current CDR

Criteria for defining CDR

As discussed in Chapter 1, we use the IPCC's definition for what counts as CDR.[1] This definition requires a way to distinguish CDR from natural carbon uptake, which is itself increasing as an indirect consequence of human changes to the environment. Specifically, plant growth is enhanced by the combination of elevated atmospheric CO_2 concentrations, global warming and nitrogen deposition. We include carbon uptake from afforestation, reforestation and forest management activities, but in calculating the resulting CDR we exclude the additional growth caused by environmental changes after establishment. Carbon sinks in unmanaged forests are also fully excluded. Calculating CDR in this way requires models and assumptions, as observations alone are insufficient.

Guided by the definition above, we focus on the annual flux of CO_2 from the atmosphere to durable storage from human activity, minus any stored CO_2 that is subsequently re-released. The wider lifecycle of CDR activities is not included (e.g. construction of facilities and transportation of materials). This aligns with the approach taken by national GHG inventories and the Global Carbon Budget,[2] whereby the emissions from other stages of the project lifecycle are allocated to the sectors in which they occur (e.g. industry and energy). Applied consistently, this approach avoids double-counting emissions and is, in some sense, intuitive: for instance, wind turbines are considered zero-emission in the power sector, while emissions associated with their manufacture, transport, installation and operation are accounted for in the industry and transport sectors.

Still, some definitions of CDR (e.g. Tanzer & Ramirez[3]) require a cradle-to-grave lifecycle assessment (LCA) to ensure that the total overall activity results in net negative emissions. LCA is informative for assessing CDR projects, and the volume of CDR credits issued by current projects is reduced because registries tend to account for lifecycle emissions (see

Box 7.1). It should be noted that our gross estimates do not guarantee net removal at the level of a whole project or system.

As set out in Chapter 1, and consistent with previous editions, we make the following additional choices:

- We exclude BECCS or DACCS projects with EOR. Currently, three such operational facilities capture a total of 0.47 $MtCO_2$ per year.
- We exclude ambient cement recarbonation, currently estimated to remove 700 $MtCO_2$ per year (around a third the size of current CDR from afforestation and reforestation). We do, however, include approaches that directly enhance recarbonation as CDR in the “mineral products” category.
- We include forest growth on abandoned agricultural land as a form of afforestation and reforestation. In many such cases, the forest cover may grow without any direct human intervention, and the abandonment may occur for reasons other than carbon removal. Even so, it can be argued that the abandonment and continuing non-use of the land reflects a human decision.

Estimating current CDR levels

Afforestation, reforestation and forest management

This report uses two largely independent approaches to quantify CDR through forest creation and management during the decade from 2014 to 2023.

The first (primary) approach estimates removals through afforestation and reforestation using data from the three bookkeeping models (BLUE, LUCE, OSCAR) used by the Global Carbon Budget.[2] Bookkeeping models combine information on land-use change, carbon contained in different types of vegetation, and response functions for different types of land-use changes to provide annual estimates of CO_2 removals and emissions from land use since 1700. Employing recent updates in Global Carbon Budget methodology, bookkeeping models incorporate environmental conditions (e.g. atmospheric CO_2 concentrations and climate) prevailing at the time new forests were being established.[4] Any subsequent environmental changes, such as those driven by increases in atmospheric CO_2 after forest establishment, are considered to be part of natural uptake.

The second (complementary) approach provides a global estimate based on aggregated national greenhouse gas inventories (NGHGIs) of emissions and removals in managed forests. Conceptually, NGHGIs include afforestation and reforestation (like bookkeeping models) plus the management of other pre-existing forests. Because NGHGIs typically include both direct human-induced effects (e.g. land-use change) and indirect human-induced effects on plant growth (e.g. CO_2 fertilization), they often report much larger forest carbon sinks than what is typically counted as CDR. To address this, we take CO_2 fluxes reported in NGHGIs under the “managed forest land” category and subtract indirect effects using estimates from dynamic global vegetation models. Acknowledging the different definitions of “anthropogenic sink” between NGHGIs and global models is important and necessary for consistent and comparable assessments of the remaining carbon budget, the timing of net zero and even the definition of net zero itself (e.g. Grassi et al. 2021[5], Allen et al., 2005[6]).

These approaches provide two complementary perspectives on conventional CDR, along with an understanding of regional patterns. Further details on the methods for quantifying conventional CDR can be found in the Technical Annex.

Peatlands, coastal wetlands and soils

Conventional CDR also includes the management of wetlands, such as the restoration of inland peatlands and so-called “blue carbon” sinks like coastal mangrove forests, salt marshes and seagrass meadows. This report does not contain estimates for CDR levels from these methods because they are not included in bookkeeping models. Some NGHGIs report small carbon sinks from wetlands (less than 1 $MtCO_2$ per year), while the United States is the only country that has reported a substantial sink (about 12 $MtCO_2$ per year, up to the year 2022) from vegetated coastal wetlands. However, disentangling the direct CDR component from the total reported carbon sink in wetlands is not currently possible.

Forest soils are included in this report, as they are incorporated in bookkeeping models and in several NGHGIs. However, CDR from soil carbon sequestration in croplands and grasslands are not included in bookkeeping models, and therefore we do not account for these fluxes in this report. Globally, NGHGIs report a net sink of about 500 $MtCO_2$ per year (on average between 2014 and 2023) from croplands and grasslands, mostly in China and India, but it is difficult to separate the CDR component from indirect effects.

Novel methods

Estimates for biochar production volumes are compiled using a survey conducted jointly with the International Biochar Initiative and the US Biochar Initiative. These volumes are converted to CDR estimates following the methodology of Woolf et al. 2021.[7] Because biochar feedstock type can significantly influence carbon content, and therefore CDR per unit biochar, production volumes are categorized by feedstock type, and literature-derived carbon contents are applied to estimate CDR. Biochar decay is accounted for using decay rates dependent on carbon content and soil temperature. Accordingly, reported biochar CDR values are adjusted to subtract CO_2 re-emitted to the atmosphere from the decay of biochar produced in previous years. Uncertainty estimates reflect variability in the reported carbon content of biomass and in soil temperatures used to calculate decay rates. As the survey data is likely incomplete, CDR estimates here should be considered lower bounds. Methodological details and further discussion are provided in the Technical Annex.

Our estimates for other novel CDR methods have been derived from a review of databases – including those maintained by the IEA, CDR.fyi, and Mission Innovation – and registry and crediting platforms such as Isometric and Puro.earth. These privately-operated registries are voluntary rather than mandatory public reporting systems, though certification is increasingly used to enable market participation and credit issuance. Our calculations were verified using a company survey conducted jointly with CDR.fyi. Because our analysis for novel methods relies on company-reported data, it is difficult to quantify uncertainty. Instead, we aim to report conservative values for each novel method that implicitly accounts for uncertainty (see the Technical Annex).

Transfers between durable carbon pools

Several CDR methods involve the transfer of captured atmospheric CO_2 from one carbon pool to another. If the intermediate pool is itself a multi-year store of carbon, there can be a separation in time between the removal from the atmosphere and the ultimate storage. This is especially applicable to woody biomass (in which atmospheric CO_2 is captured during tree growth, which is later harvested and transferred into wood products).

We track these cases as the transfer of carbon from one durable pool to another in a given year, distinct from the removal of CO_2 from the air during that same year. Carbon transfers represent reallocations of previously captured atmospheric carbon and do not generally mean that the carbon was removed from the atmosphere in that year.

The bulk of carbon transfers occur from forests to durable harvested wood products. These are estimated using Food and Agriculture Organization Statistics (FAOSTAT) data on the production of roundwood, sawnwood and wood-based panels. Because these products decay over time, some of the carbon is returned to the atmosphere. The net transfer of carbon into harvested wood products is therefore calculated as the sum of the carbon added to the durable harvested wood products pool minus the carbon returned back to the atmosphere via product decay, based on the IPCC decay functions for each commodity.[8] Note that other, less-durable harvested wood products, such as paper and paperboard, are not counted here as CDR.

FAOSTAT does not provide uncertainty estimates, making it difficult to infer the uncertainty in carbon transfers. Notably, only 15% of the country records reported by FAOSTAT are defined as "official statistics", while around 63% of the data are labelled "estimated values", with the remainder coming from external sources. Additionally, the use of default parameters within the IPCC decay functions further contributes to uncertainty in our estimates.

Novel CDR methods can also involve transfer of woody biomass, with biochar and BECCS being the two principal methods as measured by current and projected future volumes. For biochar, we record the volume of converted carbon in the year of pyrolysis from both woody and annual biomass feedstocks in our estimates of CDR activity (see Figure 7.2).

The biochar made by using woody feedstocks represents a carbon transfer, with the CO_2 capture from the atmosphere having generally occurred in a previous year. There are no current operational BECCS facilities that use woody feedstocks; however, woody biomass has been listed as a feedstock for at least 16 future BECCS-based facilities (IEA, 2025).[9]

7.2 Current conventional CDR

Estimates from the two approaches used in this assessment – bookkeeping models and model-adjusted NGHGIs – show broad agreement and point out that afforestation and reforestation currently account for the bulk of conventional CDR. In particular, CDR in afforestation and reforestation as estimated by bookkeeping models amounts to 2,200 $MtCO_2$ per year (with a range across models from 1,800 $MtCO_2$ to 2,600 $MtCO_2$ per year), averaged from 2014 to 2023. CDR in managed forests estimated by NGHGIs, including both afforestation and reforestation (like bookkeeping models) and management of existing forests, amounts to approximately 2,100 $MtCO_2$ per year (with a standard deviation of 680 $MtCO_2$ per year) between 2014 and 2023. Given the large uncertainties linked to subtracting indirect effects on CO_2 sinks reported in NGHGIs, we provide only a global value of forest CDR derived from the NGHGIs in this report; we do not offer country-specific values. Out of the total estimated CDR of 2,100 $MtCO_2$ per year, the NGHGI subcategory "land converted to forest", which contains all CO_2 fluxes in the first 20 years after land conversion to forest, constitutes approximately 900 $MtCO_2$ per year.

Globally, CDR through afforestation and reforestation as estimated by bookkeeping models increased between 2000 and the mid-2010s and has since remained relatively stable at 2,200 $MtCO_2$ per year (see Figure 7.1a). The long-term CDR increase is predominantly due to China, with additional contributions from Brazil, the Democratic Republic of the Congo, Canada, Mexico and several other countries. Over the same period, CDR rates also decreased in some places, most notably the European Union and the United States. Not all country-level trends are statistically significant. Due to the large uncertainties, it remains difficult to assess the trend in the last ten years (2014 to 2023), where CDR rates appear to have stabilized. However, the real CDR rates are likely lower than our estimates, as bookkeeping models do not account for natural disturbances affecting forest growth and permanence.[10]

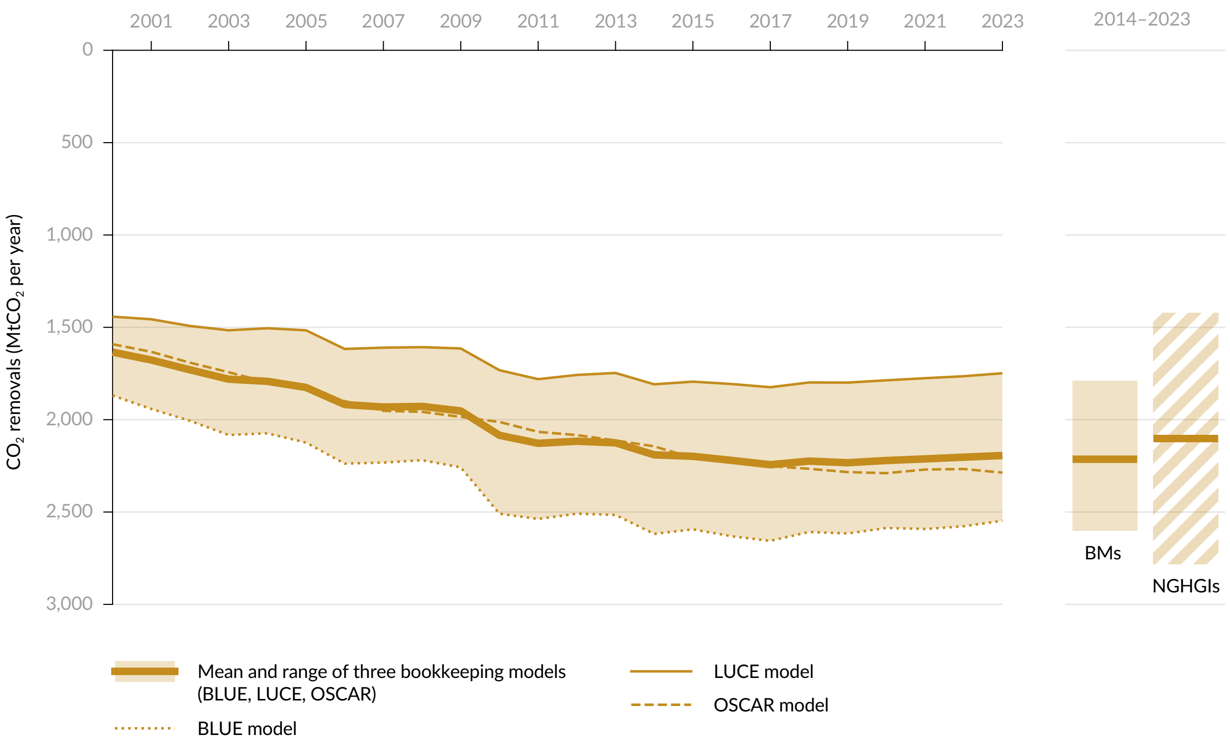
Despite broad alignment in their global estimates of conventional CDR from 2014 to 2023, bookkeeping models and NGHGIs exhibit slightly divergent trends over the longer period from 2000 to 2023: bookkeeping models show a modest increase in CDR whereas adjusted NGHGIs indicate a small decrease (see Figure 7.1a and Figure A7.3 in the Technical Annex).

Bookkeeping models indicate that the highest volume of CDR through afforestation and reforestation at the country level occurs in China, followed by the United States, the European Union, Brazil and the Russian Federation (see Figure 7.1b). Together, these contribute 55% of global CDR from afforestation and reforestation. CDR through afforestation and reforestation is most extensive in East Asia and Europe, with substantial areas in several tropical regions and parts of North America, India and the Russian Federation also providing considerable CDR (see Figure 7.1c). While the global-level estimates generated by the three bookkeeping models are similar, more substantial differences emerge at the country level, particularly for China and the European Union (see Figure 7.1b).

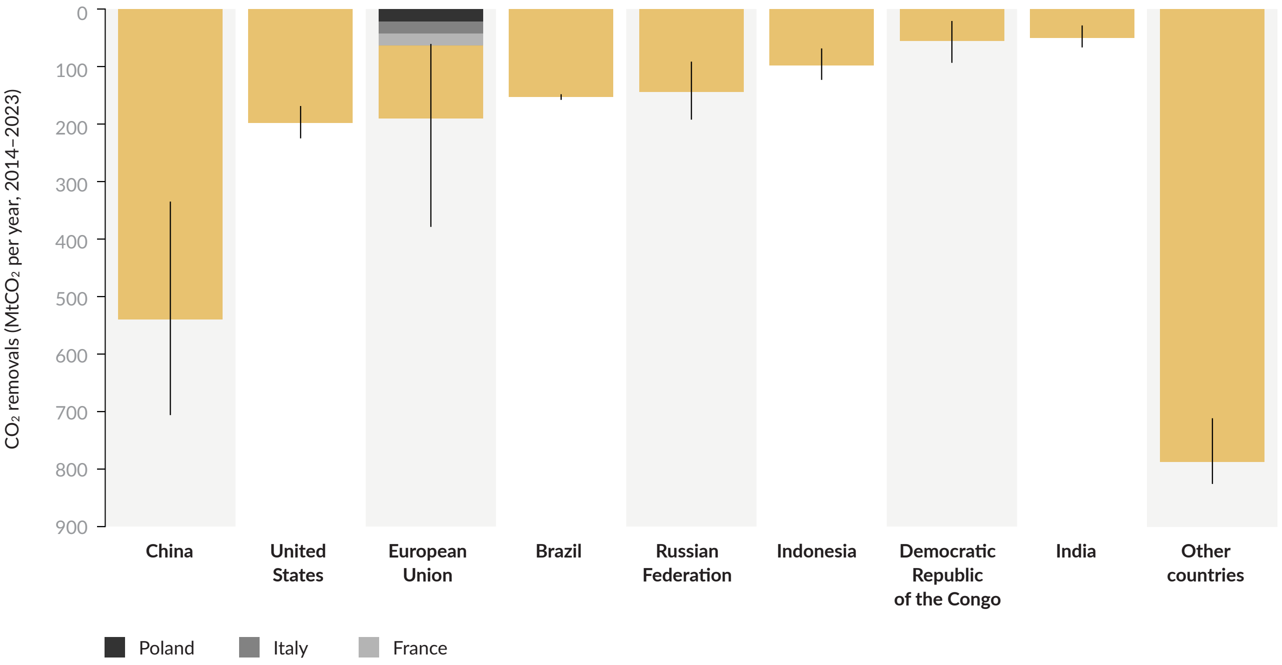
The uncertainties in CDR estimates from bookkeeping models, quantified as differences across model estimates, are substantial (around 20% for 2014 to 2023; see Figure 7.1a). Underlying these uncertainties are land-use datasets (which are partly incomplete and not fully constrained), divergent assumptions regarding carbon stocks in different types of vegetation and soil, and differences in forest growth curves.[11]

CDR rates in forests, by year and region

a) Global CDR through afforestation and reforestation



b) Country-level CDR through afforestation and reforestation



c) CDR through afforestation and reforestation

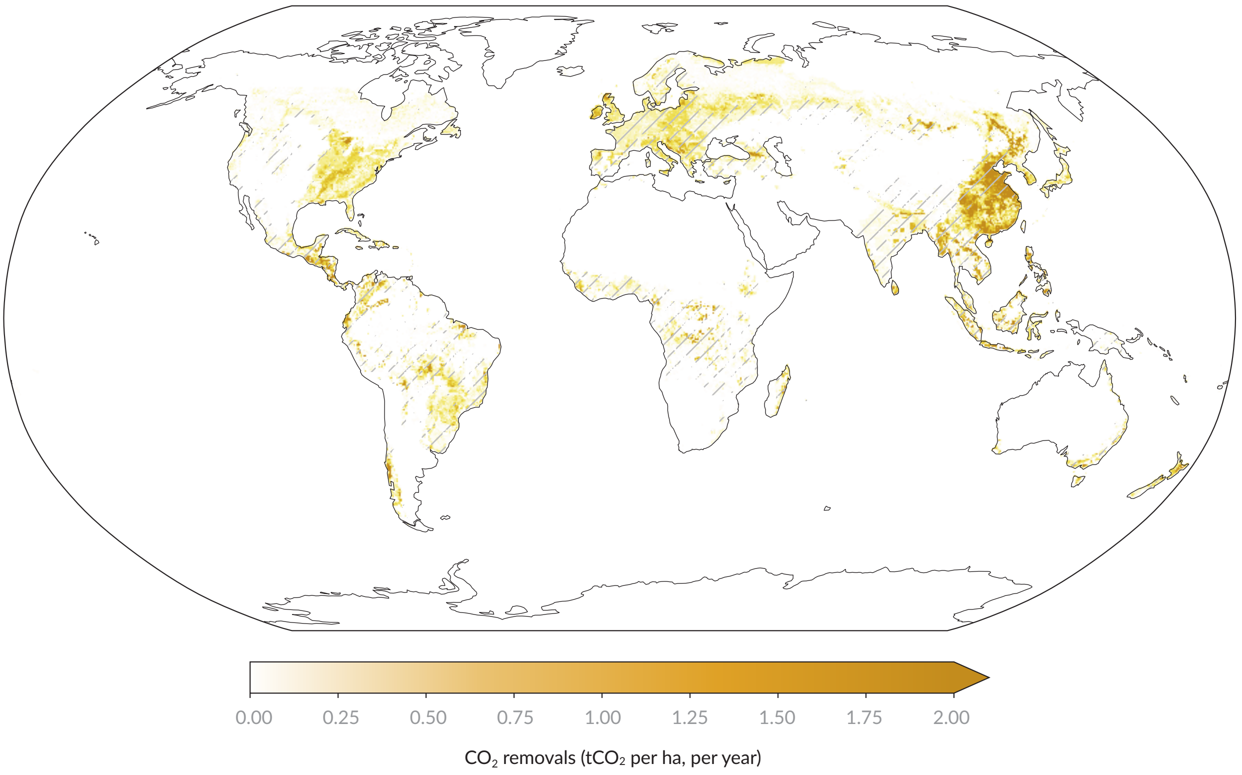


Figure 7.1 *Rates of conventional CDR by year and location. (a) Global estimates of CDR due to afforestation and reforestation, (b) estimates ranked by country and the European Union countries collectively, and (c) global map with CDR estimates. Shading in panel (a) indicates the full range across bookkeeping models and the standard deviation for NGHGIs. Values in panel (b) and panel (c) show averages of the three bookkeeping models from 2014 to 2023. Bars in panel (b) indicate the multi-model mean of the models BLUE, LUCE and OSCAR, and whiskers represent the full spread across their estimates. Country names in the European Union bar indicate the three EU countries with the largest removals from afforestation and reforestation. Grey hatching in panel (c) indicates regions of high inter-model variability (standard deviation > 0.5 × mean; hatching not shown for regions with CDR below 0.01 tCO$_2$ per ha, per year).*

7.3 Current novel CDR

CDR from novel methods grew from 1.4 $MtCO_2$ in 2023 to 2.0 $MtCO_2$ in 2025. In previous years, this total was dominated by four main methods: biochar, BECCS, enhanced weathering and DACCS. But a slightly different leaderboard emerges in 2024 and 2025.

Biochar remains the largest contributor to CDR, with a significant increase in 2025. Survey results indicate that 0.54 Mt of biochar was produced in 2025. After separating by biomass type and applying decay rates (see the Technical Annex), we estimate biochar removed 1.46 (± 0.16) $MtCO_2$ in 2025, approximately 1.9 times more than in 2023 and nearly three-quarters of total novel CDR in 2025. As our calculations use conservative assumptions, and survey data may be incomplete, this should be considered a lower bound. A comparison of the 2023 and 2025 survey responses suggests that the increase is primarily attributable to real growth in biochar production rather than improved survey coverage (see the Technical Annex).

BECCS remains the second-largest contributor. In 2025, BECCS removals totalled 0.51 $MtCO_2$, a slight decrease from 0.61 $MtCO_2$ in 2023. Three facilities were operational in 2025, all in the United States: Blue Flint Ethanol, which commenced operations in 2024; Gevo (formally Red Trail Energy); and the ADM bioethanol CCS facility in Decatur, Illinois. The Illinois facility temporarily paused injections in October 2024, following detection of fluid migration in the storage reservoir, and resumed operations in September 2025. In the absence of a complete estimate, we assume capture for the Illinois facility at its typical annual removal rate (0.43 $MtCO_2$),[9] scaled to account for the months of operation for both 2024 and 2025. This approach assumes a constant capture rate throughout the year; in practice, capture rates may fluctuate due to operational ramp-up following a pause, maintenance or other downtime. Consequently, the estimate presented here should be interpreted as an approximation, rather than a precise annual total. The apparent decrease in total BECCS removals in 2025 is primarily due to this injection pause; if the Illinois facility had been operating throughout, combined BECCS CDR would have reached 0.8 $MtCO_2$.

Biomass burial became the third-highest contributing CDR pathway in 2025, removing 0.05 $MtCO_2$, a 21-fold increase relative to 2023, but still minor compared to biochar or BECCS. This increase was driven mainly by two US companies – Vaulted Deep and Graphyte – with additional activity from companies in Australia and Namibia. Bio-oil storage was the fourth-largest contributor in 2025, with 0.006 $MtCO_2$, led by Charm Industrial and NULIFE GreenTech.

In 2025, enhanced weathering removals totalled 0.0038 $MtCO_2$, lower than the 0.03 $MtCO_2$ reported for 2023 in *The State of CDR 2nd Edition*. But this drop needs context, as it reflects a revised methodology that includes only values explicitly verifiable via public documentation (see the Technical Annex). Further, these figures represent actual quantified CDR based on in-field measurements and modelling, rather than the full potential of deployed rock. While these values suggest a decline, enhanced weathering activity expanded substantially in 2024 and 2025, with companies such as Mati Carbon and Terradot spreading approximately 50,000 tonnes of basalt across multiple regions in India and approximately 48,000 tonnes over 1,800 ha in Brazil. Because CO_2 removal occurs progressively as silicate weathering proceeds, there is an inherent time lag between rock application and CO_2 uptake, meaning that the remaining deployed rock will continue to generate additional removals in subsequent years. Estimates for both 2024 and 2025 may be conservative; the joint survey with CDR.fyi identified additional enhanced weathering activity associated with a Columbian consortium operating in the coffee sector, which reports removals but does not yet have public documentation of issued credits. Inclusion of this project would raise estimated enhanced weathering CDR to 0.013 $MtCO_2$ in 2024 and 0.014 $MtCO_2$ in 2025.

CDR in mineral products contributed 0.0022 $MtCO_2$ in 2025, primarily through CO_2-cured concrete. Much of this activity came from O.C.O Technology, a UK-based company. Notably, 11% of the CO_2 removal credited via registries to this project originated from biomass used in waste-to-energy facilities, while the remainder was captured from ambient air during curing. We do not include the latter in our estimates (see Section 7.1).

In 2025, DACCS removed 0.0015 $MtCO_2$. This appears lower than the 0.004 $MtCO_2$ reported for 2023 in *The State of CDR 2nd Edition*; however, CDR from DACCS has in fact increased 18-fold over this period. The 2nd Edition value was an estimate based on the full operational capacity of the Climeworks Orca facility, which was the only operating DACCS plant at the time.[9] Available registry data now indicates that Orca captured substantially less CO_2 in 2023 than its full capacity, requiring a downward revision of our historical DACCS estimates.

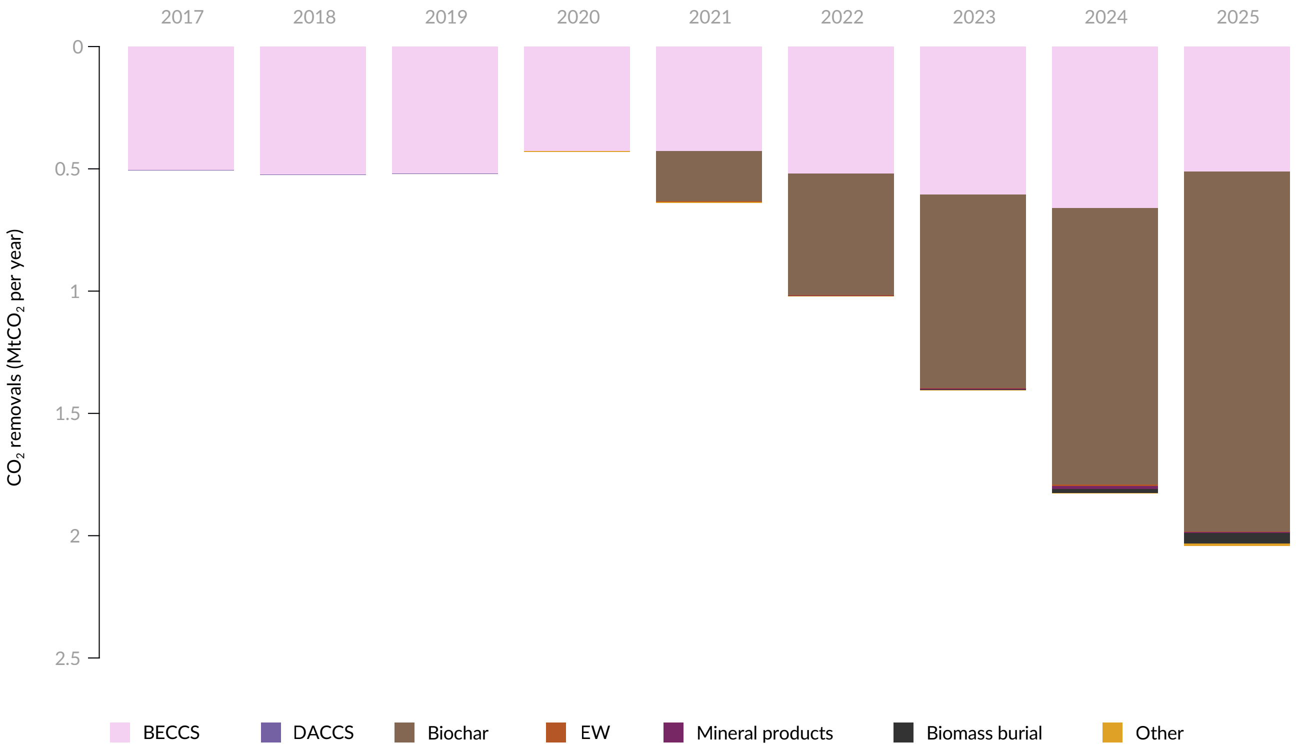
Updated values in this 3rd Edition reflect actual CO_2 capture from Orca and also from Climework's newer facility, Mammoth, which came online in 2024. Both are still operating below full capacity in 2025; however, both facilities have increased their annual removal rates from 2024 to 2025.

Values for these facilities are based on data available up to October 2025; updated registry data for the final two months in 2025 may slightly increase these totals. Company announcements also indicate that Heirloom's joint project with CarbonCure (Tracy DAC Hub; 0.001 $MtCO_2$ per year capacity[9]) is active, but as this cannot be verified via other sources (e.g. CDR.fyi) it is not included. Project Hummingbird and Deep Sky Alpha commenced in 2025, but Isometric has yet to verify any removals.

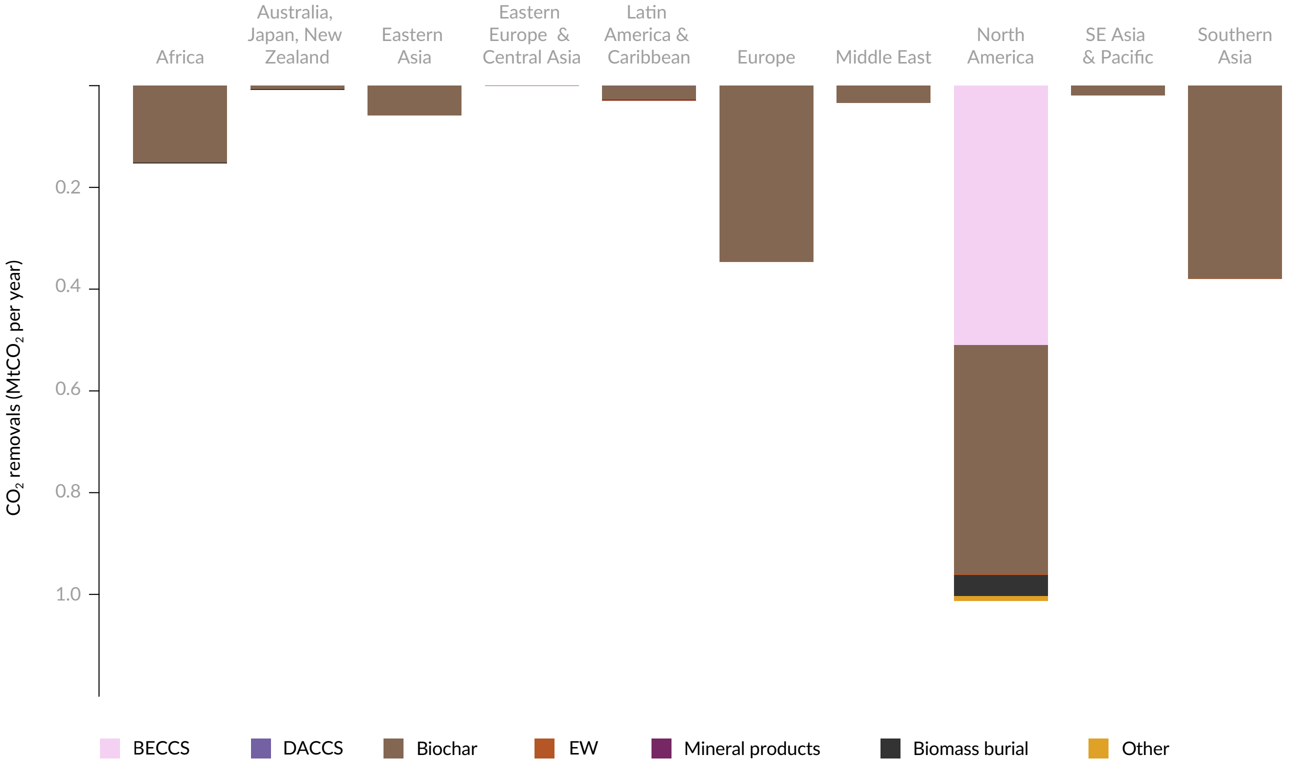
Finally, other methods, such as alkalinity enhancement of water bodies and DOCCS are also active but at smaller scale, removing a combined 0.004 $MtCO_2$ in 2025.

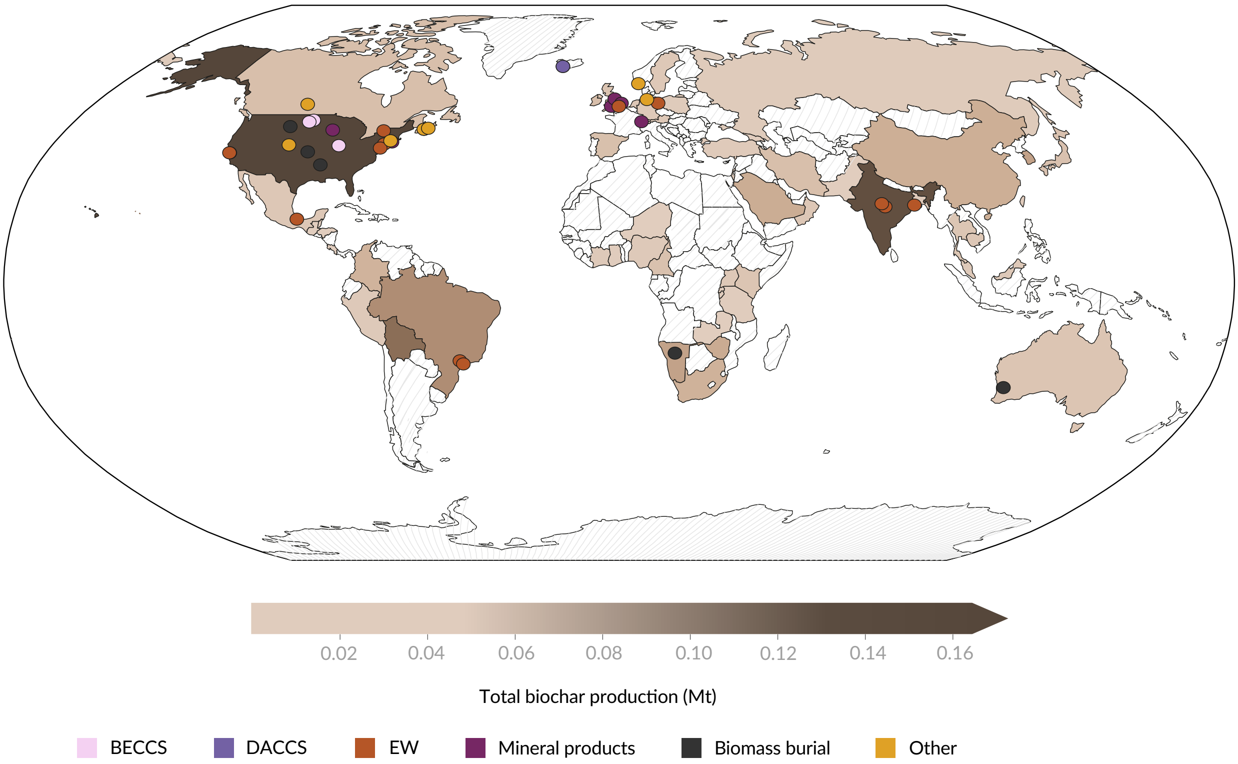
Novel CDR rates, by year and region

a) Novel CDR globally, 2017–2025



b) Novel CDR by region in 2025





c) Novel CDR by location in 2025

Figure 7.2 *Rates of novel CDR rates by year and location. (a) Global time series during 2017–2025, (b) region-specific global CDR in 2025, and (c) global map depicting biochar produced in 2025 by location, with operational sites for other novel pathways also shown (represented by coloured dots) The 2024 BECCS total includes approximately 0.32 Mt*CO_2 *from the ADM bioethanol CCS facility before injection paused in October 2024; the 2025 total includes approximately 0.14 Mt*CO_2 *from the facility after it resumed operations in September 2025.*

As noted in Section 7.1, the above estimates represent the gross amount of CO_2 moved from the atmosphere to durable storage, minus any subsequent re-release. This differs from the CO_2 removal reported in carbon credit registries for these projects, as registries tend to report net CDR after including emissions from the wider project lifecycle. When using registry data for our estimates, we have extracted the gross component only, but the net values available from these registries and other lifecycle estimates are also informative (see Box 7.1).

Box 7.1 The implication of assessing gross versus net removals for novel CDR: a lifecycle approach

LCAs for current CDR projects are available from carbon registries and scientific studies. LCA results, in general, vary widely, as studies apply different boundary conditions and methodologies.[12] There is currently no consistent approach to such assessments for CDR methods, making comparisons difficult.[13] Nevertheless, studies report that net CDR is typically much lower than the gross total CO_2 captured from the atmosphere. Here, we briefly summarize what is usually included (or excluded) in available project LCAs, and what they imply for four of the primary project types currently delivering novel CDR.

BECCS with bioethanol: In bioethanol-based BECCS projects, CO_2 is captured during ethanol production from biomass. Two distinct LCA boundary choices may be applied. When a CO_2 capture unit is retrofitted onto an existing bioethanol plant, the counterfactual baseline for LCA assumes ethanol production would have occurred anyway. This means emissions are counted from CO_2 capture, compression, processing and injection.[14] With this system boundary, net removal may be only 2%–13% below gross CO_2 captured (represented as the upper end of the range in Table 7.1). By contrast, whole-system LCAs draw boundaries around the wider bioethanol system – including direct and indirect land-use change, biomass cultivation, harvesting and bioethanol production. This broader boundary substantially reduces net CO_2 removal. In some cases, bioethanol facilities with CCS may become net emitters to the atmosphere (the value of -68% in Table 7.1 indicates that for every 1 tCO_2 captured, 1.68 tCO_2 is emitted). Replacing fossil fuels in bioethanol production with low-carbon energy would significantly improve net removal.[15]

DACCS: LCA boundaries for DACCS facilities generally include equipment manufacture, emissions during capture and processing of the CO_2 and transport into geological storage.[14] The net carbon balance is strongly dependent on the carbon intensity of the energy supply.[16] While many DACCS projects are currently under various stages of planning, only two have traceable online LCA documentation at the time of writing: Orca and Mammoth. These facilities have relatively low emissions associated with their energy supply because they are powered by a nearby geothermal source. Nevertheless, even with renewable energy, reported LCA emissions have varied substantially, reducing net removals to 23%–90% of gross values (see Table 7.1).[17,18]

Biochar: Biochar is produced from a range of biomass feedstocks, many of which are waste or residue streams from other production systems (e.g. wood waste, agricultural residues and manure). Where waste biomass is used, avoided emissions from the baseline scenario where it would otherwise decay or be combusted are not credited. Emissions associated with land-use change or biomass cultivation are usually allocated to the co-product rather than to biochar,[19] although these emissions are included where biomass is cultivated specifically for biochar production. Emissions from feedstock transport and pyrolysis are always included. Although biochar application can influence soil carbon dynamics – such as by enhancing plant CO_2 uptake or increasing soil organic carbon[20] – any additional carbon accumulation beyond the biochar is not credited. Biochar decay is also accounted for, with registry protocols applying durability adjustments over 100 years (i.e. puro.earth)[19] or 200 years (i.e. Isometric)[21] following methods derived from Woolf et al. (2021). Overall, net removals are approximately 60%–92% of gross CO_2 captured in biochar (see Table 7.1), with the range due to differences in decay accounting and inclusion of biomass growth and harvesting in LCA emissions.

Enhanced weathering: Emissions from mining, grinding, transport, spreading and monitoring are typically included in enhanced weathering LCAs. Emissions can vary widely between projects, depending on whether waste fines are used or fresh rock is mined, as well as the transport distance. Consequently, deductions from gross CDR can vary considerably between individual projects. Across current enhanced weathering projects listed on registries, deductions from gross CDR to reflect LCA emissions average 6% but range from 5% to as much as 43%. In addition, LCAs apply further, often conservative, deductions to account for uncertainty in carbon losses during transport between application sites and long-term storage in the ocean. These adjustments, which can oversimplify site-specific processes and remain conservative pending improved coupled ocean-atmosphere modelling, lead to an average reduction in removals to 68% of gross CO_2 captured (gross CO_2 stored durably, see Table 7.1). The overall net removal range reported in Table 7.1 (28%–79% of CO_2 captured) is derived directly from project-level registry data, in which both LCA emissions and potential CO_2 re-release are incorporated, rather than being calculated from the average deduction values presented above.

Gross CDR reductions due to CO_2 losses and emissions

	Gross removal		LCA emissions					Net removal range
CDR method	Gross CO_2 captured	Gross CO_2 stored durably	LUC/ iLUC	Feedstock sourcing	Feedstock processing	Capture/ transport	Burial/ injection/ monitoring	Net CO_2 removed
BECCS	100%	100%	✗	✗	✗	✓	✓	-68%–98%
DACCS	100%	99% (99%–100%)	n/a	n/a	n/a	✓	✓	23%–90%
Biochar	100%	92%–99%	✗	M	✓	✓	✓	60%–92%
EW	100%	71% (44%–85%)	n/a	M	M	✓	✓	28%–79%

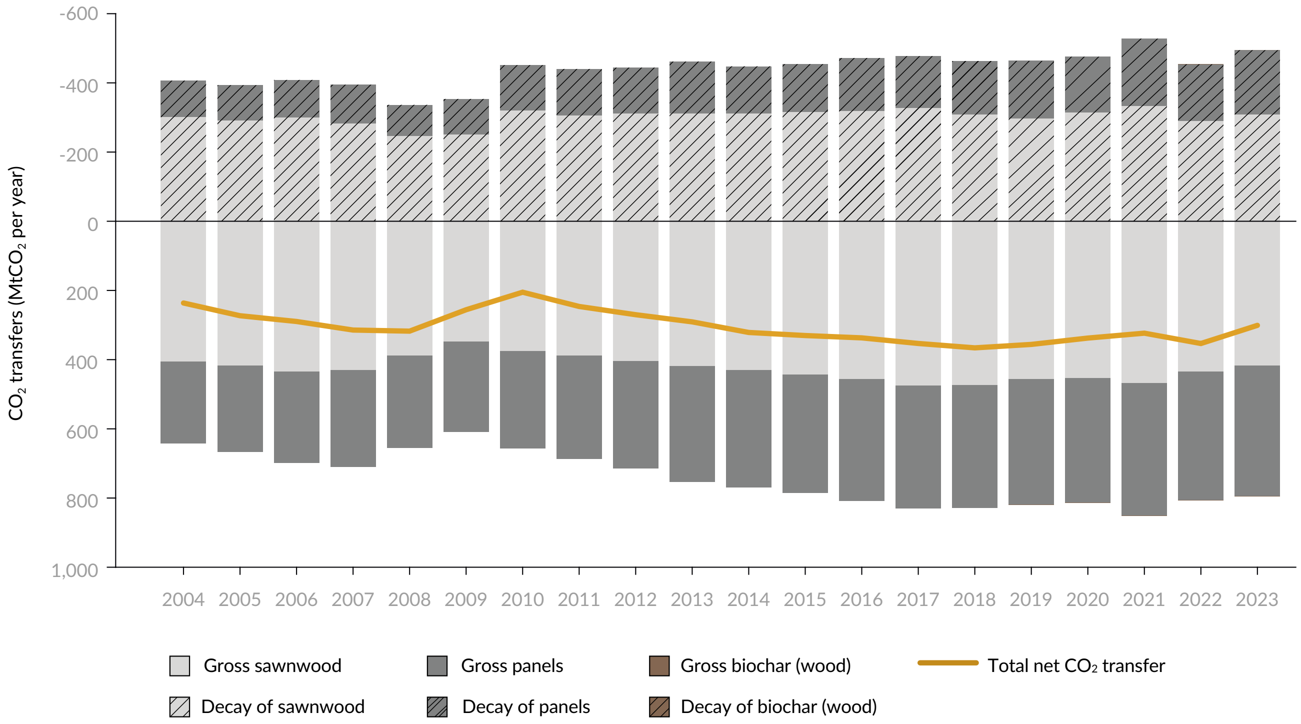
Table 7.1 *Note: Gross CDR reductions due to CO_2 losses and emissions. Percentage reductions are based on data compiled from registries and peer-reviewed LCA studies.*[15,22,23] *After initial atmospheric CO_2 removal (gross CO_2 captured), losses from downstream processes reduce this value (gross CO_2 stored durably). The LCA emissions panel shows typical cradle-to-grave emissions components across the full system boundaries. For each method, LCA components are marked either with a tick (included), cross (excluded) or M (sometimes included) based on current registries. The net CO_2 stored illustrates how LCA coverage impacts overall reductions, with the range reflecting varying LCA boundaries. LUC refers to direct land-use change, and iLUC represents indirect land-use change. The negative value for BECCS (-68%) is estimated by Dees et al. (2023)*[15] *and indicates net emissions for a bioethanol facility when considering the whole system, including co-products.*

7.4 Carbon transfers between durable stores

The transfer of carbon between durable stores can represent part of a CDR activity, though it does not generally reflect withdrawal from the atmosphere in that same year. The transfer of carbon to durable harvested wood products amounts to 780 $MtCO_2$ per year averaged over the period 2014 to 2023. The net flux of durable harvested wood products, considering also the re-release of CO_2 through their decay, amounts to 330 $MtCO_2$ per year averaged over the period 2014 to 2023 (see Figure 7.3).

The total CDR from biochar represented in Figure 7.2 includes CDR via all feedstocks used to produce biochar. Of the total CDR from biochar in 2025 (1.46 $MtCO_2$), 67% came from woody biomass, representing 0.97 (woody biomass transfer post decay) $MtCO_2$ of net carbon transfer between durable stores in addition to sawnwood and panels (see Figure 7.3).

To avoid overestimating total CDR, these carbon transfers relating to CDR should not be added directly to the above removals from afforestation and reforestation estimated by bookkeeping models. This is because the carbon transfers into harvested wood products may originate from long-managed forests, or from recently afforested or reforested areas. In the former case, the contribution is additional to CDR from afforestation and reforestation estimated by bookkeeping models. In the latter case, part of the carbon removal associated with harvested wood products may already be accounted for by bookkeeping models during forest growth in afforested and reforested areas, potentially resulting in double counting.



CDR transfers between durable stores

Figure 7.3 *Annual time series of net CO_2 transfer from biomass to durable storage (sawnwood, panels and biochar), accounting for re-release through decay, with methods detailed in the Technical Annex. Total net CO_2 transfer is the total net transfer from sawnwood, panels and biochar combined (gross – decay). Note that biochar fluxes in and out are much smaller than hardwood products and thus hardly visible in the figure. Sawnwood refers to wood cut directly from logs into products such as planks, beams or boards (>6 mm thick), while wood-based panels are manufactured products made from wood fibres, particles or veneer sheets, such as plywood and fibreboard.*

7.5 CDR deployment pipeline

Conventional CDR is expected to remain the dominant form of carbon removal in the near term, but forecasts of CDR from afforestation, reforestation and land management activities are not generally available. Near-term demand will be driven by a range of factors including policy goals and land-use pledges (see Chapter 8) alongside a small contribution from the VCM (less than 1% of current removals; see Chapter 4). However, broad government commitments do not necessarily translate directly into defined projects under active development.

For novel CDR, company ambitions total approximately 42 $MtCO_2$ per year of removals by 2030 (see Chapter 3). However, many of these ambitions do not necessarily provide concrete details of upcoming projects and are thus speculative and subject to change.

A more grounded estimate of the near-term pipeline for novel CDR is obtained by assessing projects currently under construction alongside the operations of existing projects. Estimates of the capacities of DACCS and BECCS facilities under construction are available from the IEA.[9] Based on these estimates, projected CDR reaches 0.55 $MtCO_2$ per year from DACCS and 4.8 $MtCO_2$ per year from BECCS by 2030 (see Figure 7.4). These values assume that these facilities achieve their estimated capacities and are not subject to permitting, financing and MRV bottlenecks.

Our biochar estimates draw on short-term CDR targets in documentation from operating projects, currently only publicly accessible for companies listed on Isometric. The projected additional 1.5 $MtCO_2$ per year by 2030 should therefore be considered conservative, particularly as survey data indicate that commercial and non-commercial pipeline ambitions may exceed 3 $MtCO_2$ per year by 2030.

Furthermore, rock spread through enhanced weathering projects is expected to continue providing CDR in the years ahead; based on data compiled from publicly available documentation, this could contribute an additional 0.1 $MtCO_2$ of removals. Taken together, these projections suggest novel CDR capacity could increase to approximately 8.4 $MtCO_2$ per year by 2030.

Estimated annual pipeline of novel CDR capacity, 2023–2030+

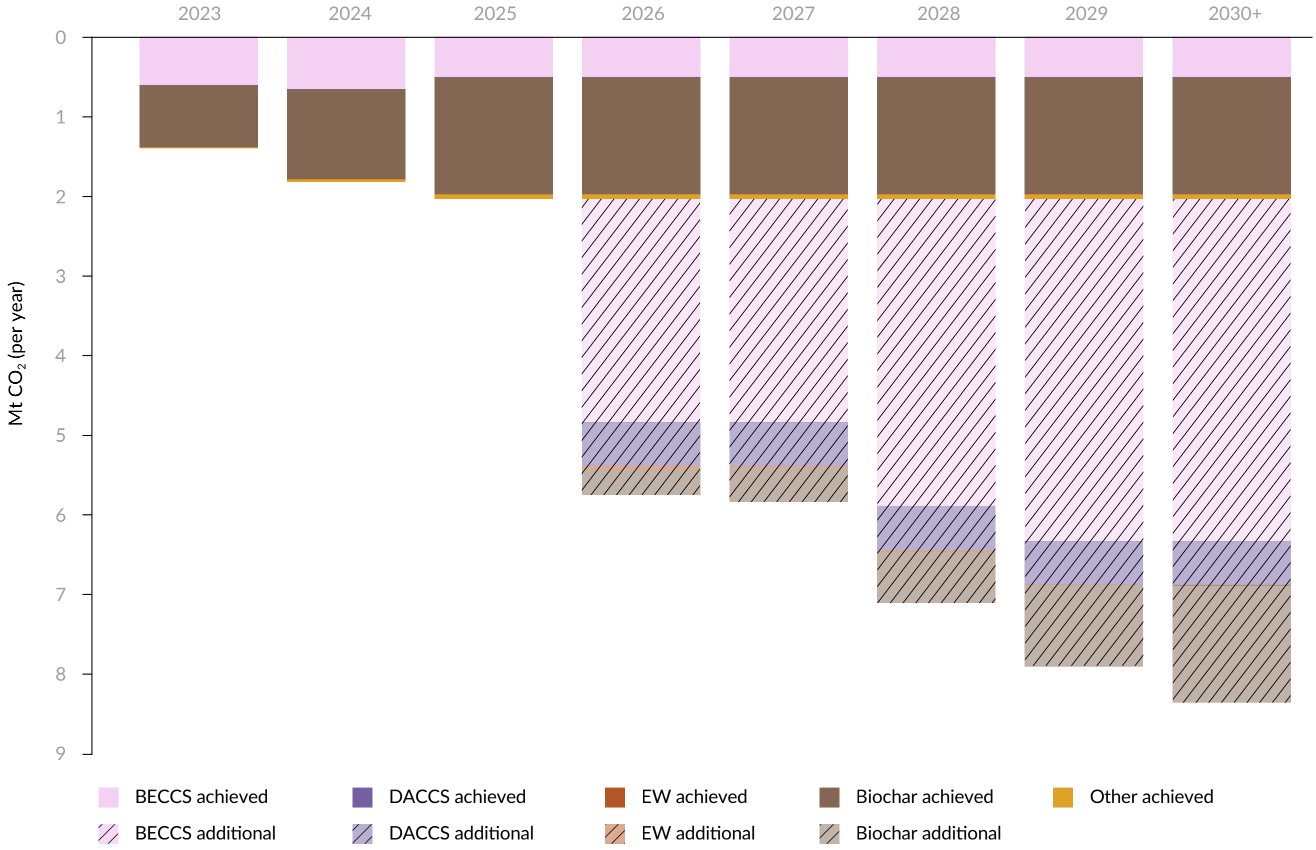


Figure 7.4 *Solid bars show achieved novel CDR for 2023–2025 and 2025 levels carried forward for 2026–2030. Faded patterned bars indicate additional capacity from new or scaling projects for 2026–2030. Note that for EW and DACCS, actual CDR is much smaller than BECCS and biochar so is hardly visible here. For BECCS, DACCS and biochar, the CDR capacity from new facilities under construction is included. For EW, values include only rock spread that has yet to deliver CDR.*

Comparing 2025 deployment with previous projections

The State of CDR 1st Edition, drawing on company announcements about planned facilities, projected that novel CDR deployment could increase eleven-fold from 1.0 $MtCO_2$ per year in 2022 to over 11 $MtCO_2$ per year by 2025. However, actual deployment in 2025 merely doubled to 2.0 $MtCO_2$. A major reason for this more modest expansion was the hold placed on the Summit Carbon Solutions BECCS project in the United States, which had intended to capture CO_2 from 30 Midwestern bioethanol plants and transport it via pipeline to North Dakota for permanent storage. In 2025, however, pipeline construction was suspended until 2028 due to local opposition.

The difference between what was projected and what actually occurred highlights the challenge of forecasting growth in novel CDR. Projects often face schedule delays, operational issues and financial, regulatory or technical constraints; these may produce knock-on effects that diminish operational capacity and delay or prompt the cancellation of the project. Consequently, not all capacity from the pipeline projects shown in Figure 7.4 may materialize.

Box 7.2 Limitations and knowledge gaps

Several improvements in our analysis of CDR capacity have been made since *The State of CDR 2nd Edition*, including updates to data sources, methodological refinements and expanded coverage of both conventional and novel CDR approaches. Nonetheless, some gaps and limitations remain. These are covered in the Technical Annex and summarized here.

- Distinguishing CDR from natural fluxes: Clearly delineating the effects of direct human activity on land from the indirect effects resulting from a changing environment is challenging, as observations alone are insufficient. Bookkeeping models have an internally coherent framework for this separation, but uncertainty is present from differing assumptions across the models, simplifications of complex land processes and poorly constrained input parameters. The estimates of CDR from NGHGIs are even more uncertain, as they rely on the subtraction of indirect effects in managed forests using dynamic global vegetation models.

- Improving the comparability of CDR estimates from bookkeeping models and NGHGIs: Bookkeeping models estimate CDR from afforestation and reforestation. By contrast, many NGHGIs report “land converted to forest” (which contains CO_2 fluxes in the first 20 years after land conversion) as well as fluxes from management of other, pre-existing forest land. It may be possible to improve comparability by extracting equivalent fluxes from bookkeeping models, which are currently not available.

- Accounting for re-release of CO_2 in forests: Bookkeeping models do not account for disturbance events. This means that their CDR estimates for afforestation and reforestation exclude changes in durability due to wildfires, droughts and similar effects. This may lead to an overestimation of conventional CDR, particularly under continued warming, and has implications for the long-term reliability of conventional CDR. The estimate of CDR in managed forests based on NGHGIs does capture such changes to some extent.

- Reconciling forest-based commitments with realized carbon removals: Estimates of near-term deployment of conventional CDR to meet forest-based restoration pledges and forward crediting commitments are constrained by limited information on the timing, location and extent of implementation. Commitments are typically reported as aggregate land-area targets or anticipated credit volumes, without systematic linkage to observed land-use change or national inventory reporting, making it difficult to assess whether pledged areas are already included in existing estimates. Although bookkeeping models can quantify removals where activities are implemented and reported, uncertainties related to implementation, additionality, durability and potential overlap across policy pledges, national inventories and voluntary carbon market claims limit the reliability of forecasts of realized removals resulting from such commitments.

- Computing downstream CO_2 loss via enhanced weathering and alkalinity enhancement: These novel methods have advanced rapidly in recent years, prompting community efforts to develop accounting protocols. For example, many enhanced weathering projects apply a uniform 20% reduction to gross CDR to account for re-equilibration of weathering products with ocean waters, plus further reductions for additional loss processes such as carbonate precipitation. While intentionally conservative, these loss allowances remain highly uncertain.

- Accounting for the re-release of CO_2 from biochar: Our estimates of CDR from biochar now include CO_2 re-released through decay. These estimates are strongly influenced by soil temperature, which varies in space and time, but only country-level data is available for biochar applications. We therefore use national average annual soil temperatures to calculate decay. While we adopt conservative assumptions and estimate the uncertainty arising from variations in soil temperature, more spatially explicit data would enable refinement for future editions.

- Highlighting gaps in tracking CDR activities: Not all current activities that may lead to CDR are tracked in this chapter. Among the likely largest missing contributors are peatland and coastal wetland restoration, and soil carbon sequestration in croplands and grasslands. Activity data for biochar (and some other projects) relies on survey responses. Such surveys are unlikely to capture all projects, particularly those by smaller producers, meaning that total activity is likely underestimated.

7.6 Outlook

CDR is being deployed with different methods in a wide variety of locations around the world (see Figure 7.5). By far the most widely deployed method is afforestation and reforestation, with removals totalling around 2,200 $MtCO_2$ per year on average over the last decade. A significant amount of woody biomass is transferred from forests into durable products, although their gradual decay leads to substantial CO_2 re-release as well. Novel CDR methods delivered removals of around 2.0 $MtCO_2$ globally in 2025, led by biochar and followed by BECCS, biomass burial and mineral products. Of this, 0.51 $MtCO_2$ is stored in geological formations and minerals, the most durable forms of storage. While these amounts are far smaller than conventional CDR rates, novel CDR has been growing at a faster rate – around 36% from 2020 to 2025.

Some significant limitations and knowledge gaps hamper our ability to track CDR developments, leading to uncertainties in our estimates (see Box 7.2). Improvements in methodology, as well as changes in real-world activity, may push future estimates lower or higher.

Current levels of CDR deployment are much lower than current gross CO_2 emissions, which amount to about 44,000 $MtCO_2$ per year.[2] The current CDR rates are also lower than the future levels of CDR required even in pathways that reduce emissions deeply to meet climate goals (see Chapter 8). While this chapter finds a number of CDR projects in active development, which should lead to a further increase in capacity, recent history shows that delivery tends to be lower and slower than such capacity projections indicate.

Summary of current atmospheric fluxes and transfers from CDR activities

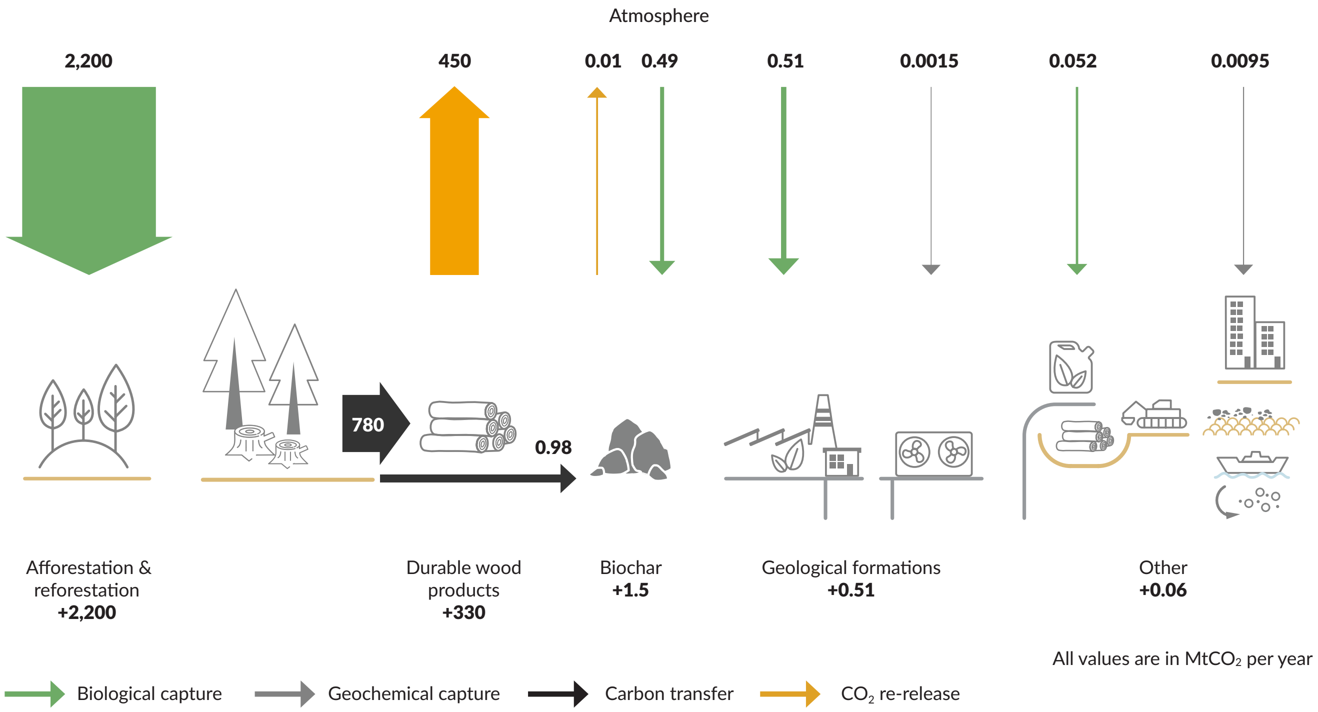


Figure 7.5 *Summary of current atmospheric CO_2 fluxes and transfers from CDR activities based on average conventional CDR levels between 2014 and 2023, and estimated novel CDR in 2025. Downward arrows indicate fluxes out of the atmosphere due to CDR activity, while upwards arrows indicate fluxes back into the atmosphere from storage. Conversion of woody biomass is indicated as a carbon transfer (horizontal arrows); transferred carbon is typically captured from the atmosphere in previous years. Durable carbon stores are labelled at the bottom, along with net changes in CO_2 stored (bold numbers). All numbers shown to two significant figures.*

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